AD-A159 899 ANNUAL SUMMARY REPORT FOR ONR CONTRACT NUMBER N00014-81-K-0011 INVESTIGAT..(U) CALIFORNIA UNIV LOS ANGELES DEPT OF MATERIALS SCIENCE AND ENG.. K ONO 1/1

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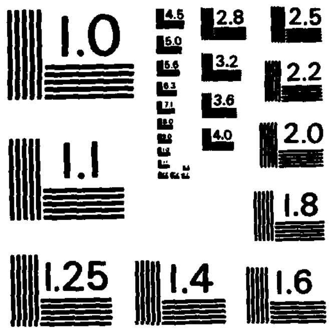

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ANNUAL SUMMARY REPORT

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AD-A159 899

Submitted to

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REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER	2. GOVT ACCESSION NO. AD-A159 299	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Annual Summary Report		5. TYPE OF REPORT & PERIOD COVERED Technical
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Kanji Ono		8. CONTRACT OR GRANT NUMBER(s) N00014-81-K-0011
9. PERFORMING ORGANIZATION NAME AND ADDRESS Materials Science and Engineering Department 6532 Boetler Hall Los Angeles, CA 90024		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 61153N NR 384-700 RR011-08-01
11. CONTROLLING OFFICE NAME AND ADDRESS Physics Division ONR-800 North Quincy St. Arlington, VA 22217		12. REPORT DATE September 1985
		13. NUMBER OF PAGES 7
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

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17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Acoustic Emission	Fe-Ni alloys
Heat Treatment	Glass-fiber reinforced composite
A533B Steel	Magnetomechanical acoustic emission

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report summarizes the activities and accomplishments of this contract investigation from November 1984 to present.

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This investigation is aimed at studying acoustic emission for applications to residual stress measurements and for the evaluation of structural integrity of engineering structures. Effects of microstructure, composition and prior cold working on magnetomechanical acoustic emission (MAE) have been studied. Magnetization behavior, magnetostriction and Barkhausen noise are affected by stress as well as other parameters. These responses will be measured simultaneously in order to identify the stress level uniquely. Combinations of advanced signal analysis methods and MAE measurements appear to provide the most promising NDE methods at present, and have been studied to identify the optimum parameters for applications.

In the second part of this study, acoustic emission from materials undergoing plastic deformation and fracture has been examined in an attempt to improve detection capability of the impending structural failure. Our previously established techniques are extended in studying the acoustic emission behavior of advanced aluminum alloys and composite materials. Digital signal analysis techniques are used to investigate further the different types of acoustic emission signals from various sources. A major emphasis has been placed on the fracture related AE in high strength aluminum-lithium alloys and fiber-reinforced advanced composites including metal matrix (Al-SiC) and resin matrix (graphite-epoxy) materials.

STUDY 1

Stress waves arising from magnetostriction of ferromagnetic materials are called magnetomechanical AE. The basic cause involves magnetostriction during magnetic domain wall movement. Potentials for practical applications as a new method for residual stress measurement are very high, but competing effects from microstructural changes must be factored out.

We have generated the basic knowledge on MAE during the past several years. From simultaneous measurements of MAE, magnetization (B-H) curve, magnetostriction and Barkhausen noise, much information has been accumulated. Our study has employed Fe, Ni, Fe-Ni alloys and Fe-Si alloys and test temperature, stress, microstructures and amount of cold work have also been varied. Relying on the results of the basic MAE study, we have continued to explore several different schemes for practical implementation of MAE for residual stress applications. The most promising one relies on the intensity ratio of MAE at different field or frequency ranges. A number of other combinational approaches are also evaluated. The eventual goal of this study is to utilize all the available data on MAE and magnetization for separate identification of residual stress, prior cold work, chemical composition and heat treatment.

During the past year, MAE studies for basic understanding of its origins using Fe, Ni and their alloys were completed and three papers were published based on M. Kwan's Ph.D. thesis. The first one (Ref. 1) dealt with the low-field MAE behavior that parallels the variation in dB/dt and magnetrostriction. understand AE characteristics. The second one (Ref. 2) established that rotation of magnetization vector contributes little to MAE and that a second MAE peak discovered at high magnetic field region was due to

the elimination of small island domains (known as Neel spikes in some cases). The third (Ref. 3) dealt with temperature dependence of MAE signals. This work was presented at the 13th EWGAE Meeting and at the 7th International AE Symposium (Ref. 4).

A new student, O.Y. Kwon, has been working in this area. He has explored practical applications of MAE. So far, he has obtained envelopes of MAE and Barkhausen noise (BN) signals from 25 differently heat treated A533B steel samples. Five envelopes were determined for each sample and stored in a microcomputer. These waveform data were then processed using a pattern recognition analysis software and classified according to heat treatment. Nearly perfect classification was achieved. This indicates that we can detect differences in steel heat treatment via MAE and BN signals.

STUDY 2

This part of the project attempts to establish the basic understanding of AE from structural materials in order to provide a firm foundation on which one can utilizes AE as a tool for NDE applications. It is important to identify the origins of different types of acoustic emission. We have studied AE associated with plastic deformation and fracture of structural alloys, in particular, a nuclear pressure vessel steel (Type A533B). Our previous studies have discovered the dominant role of emissions arising from non-metallic inclusions in steels.

AE study of nuclear reactor vessel steels, A533B type, has been continued to correlate fracture mechanisms and various characteristics of AE signals. These have been completed. The first part concerns test temperature effects that encompass ductile and brittle ranges using two orientations with or without readily separable nonmetallic inclusions. The second was on the interfacial separation and cohesion at MnS inclusion/matrix interfaces via thermal treatment. The third is on the nature of specific fracture mechanisms that manifest themselves on AE signal characteristics. H.B. Teoh's Ph.D. thesis was completed in October 1984. Three papers were published (Ref. 5-7) and one is being reviewed (Ref. 8). One additional paper is in preparation, concerning temperature dependent AE characteristics of A533B steel. Two talks were presented on the topic of Refs. 7 and 8 at the 27th AEWG Meeting and at the 7th International AE Symposium (Ref. 9).

Another approach for AE signal characterization is the use of digital signal processing. Because of the complexity of this method, only a limited number of AE events have been analyzed at the present time. Our initial results have indicated that a clear distinction is feasible between AE signals detected during the plastic deformation of notch-tip and those from crack propagation. This is based on pattern classification using autoregressive modeling. A report is being prepared on this subject and will be presented at the Second International Conference on AE (Ref. 10).

We have investigated AE behavior of pressure vessel steels and identified most of the sources. When AE is used as an NDT method, most AE signals are generated at weldments. While the metallurgy of welding is quite complex, we must elucidate the nature of AE signals from welds in order to determine whether a detected AE comes from a crack or other innocuous sources. For this purpose, we have obtained a weldment of 4" thick plate with multi-pass welding. This was especially prepared from an A302B steel plate. Tensile and Charpy bend samples were machined from various sections of this plate, including welds heat-affected zones and the parent metal. AE characteristics were determined by conventional and advanced instrumentation and correlated to microstructures, inclusion content and stress relief treatments. The welds and matrix have been found to be extremely clean. No significant AE signals have been detected that differentiate defective regions of welds or heat affected zones. Thus, we have to abandon this project. We plan to present the AE characteristics observed by combining with an earlier study on very low sulphur low alloy steels conducted by O. Y. Kwon and I. Roman (Ref. 11). In the latter, we used steels containing 0.0005% and 0.006% sulphur. No inclusion related burst emissions were found in the very low sulphur steel even when short transverse direction samples were tested.

Another area that requires special attention is AE from composite materials. Advanced fiber reinforced composites with metal and resin matrices have been used in increasing numbers in a variety of naval aircrafts and weapons systems. Yet, NDE techniques leave much to be desired. AE has been used to locate flaws in numerous missile motorcases. However, the nature of emission processes has not been clarified in many instances. This is especially true in metal matrix composites (MMC), and we attempt to rectify this situation. Al-base metal matrix composites have been investigated extensively by various DoD laboratories, including NRL and NSWC. Their properties are still short of desired toughness and strength levels. It is hoped that AE due to whisker-matrix interaction and whisker fracture can aid in improving the properties and provide an NDT method when actual hardwares are built.

We have obtained an MMC plate with 15 wt.% SiC whiskers, a comparable powder processed Al alloy plate and a wrought plate. We have also received a 25% SiC composite plate from Dr. Divecha of the NSWC and 20% and 30% SiC particulate composites from DWA Composites Specialty. These have been prepared into tensile and fracture test samples and heat treated to several different toughness levels. Various AE parameters were determined and related to mechanical and metallurgical properties.

These metal matrix composite samples were investigated during tensile and fracture tests as a function of heat treatment. As-notched Charpy specimens were used in three-point slow bend tests. Five material conditions were compared (as-received, T4 and three T6) as well as four other alloys (Ingot 2024, 2224, 2034 and P/M 2124). For a given material, samples in the T6 conditions exhibited similar AE behavior. The 2024 alloy had substantially higher AE event rates than either P/M 2124 alloy or MMC. The MMC gave unique AE behavior in the T6 conditions characterized by increased event counts in the load range of 50-80% fracture load and then low counts until failure

occurred. In order to differentiate several possible sources of emissions, we are presently testing transverse direction samples and examining metallographically the fracture surface morphologies. This study will be presented at the Second International Conference on Acoustic Emission, Lake Tahoe, Nevada, October, 1985 (Ref. 12).

New structural aluminum alloys are attracting much attention lately. These are lithium containing alloys and the NSWC is the key agency that has been involved in developing them. Basically, these contain a few wt. % Li, have higher strength and modulus than regular Al alloys with a density of up to 10% less. Metallurgical characteristics still are not as well known as other existing alloys, although these have been studied intensively in recent years.

Presently, we have three such alloys and started to evaluate their AE behavior as a function of alloy composition and heat treatment. Materials were obtained from Lockheed California Co. and ALCOA. Initially, Lockalite B is studied and AE parameters have been obtained for five different heat treatment conditions. We find that this alloy behaves entirely different from normal high strength aluminum alloys. Specifically, AE intensity increases with increasing yield strength as the alloy is aged following solution heat treatment. Dynamic strain aging effects are also quite substantial. Initial results will be presented at the Second International AE Conference, Lake Tahoe, NV, October 1985 (Ref. 13).

This class of high strength aluminum alloys will become a very important part of future aircraft structures (possibly replacing many components expected to be made from composite materials). Thus, we plan to devote a major effort in this area, as one must gain better understanding of microscopic mechanisms from AE analysis and provide an NDE method once hardwares are built from these materials. A new student, J. Zamiski, has started to survey materials studies conducted so far and will investigate deformation and fracture of these alloys using AE as the principal technique.

Several presentations on related topics are listed in the reference section. These include a talk on glass-epoxy composites, residual stresses and general acoustic emission (Ref. 15-18).

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14. C.H. Johnson, I. Roman and K. Ono, "Progress Report on Acoustic Emission Studies of Composite Materials and Structures," presented at the 27th AEWG Meeting, San Antonio, TX, 4-7 February 1985.

15. I. Roman and K. Ono, "Acoustic Emission Characterization of Fracture Mechanisms in Woven Roving Glass-Epoxy Composites," Progress in Acoustic Emission, II, eds. M. Onoe et al, Japan Soc. NDI, Tokyo, 1984, pp. 496-503. Also presented at the 27th AEWG Meeting, San Antonio, TX, 4-7 February 1985.

16. K. Ono (invited seminar), "Acoustic Emission," Brookhaven National Laboratories, Upton, NY, 13 July 1984.

17. K. Ono (invited lecturer), "Magnetic and Ultrasonic Techniques and Evaluation," Residual Stress Measurement and Analysis, Engineering Short Course, Union College, Schenectady, New York, 9-11 July 1984.

18. K. Ono (invited lecturer), "Ultrasonic Stress Measurement Methods," Residual Stress Analysis, Workshop, Society of Experimental Mechanics, Los Angeles, CA, 25-27 March 1985.

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